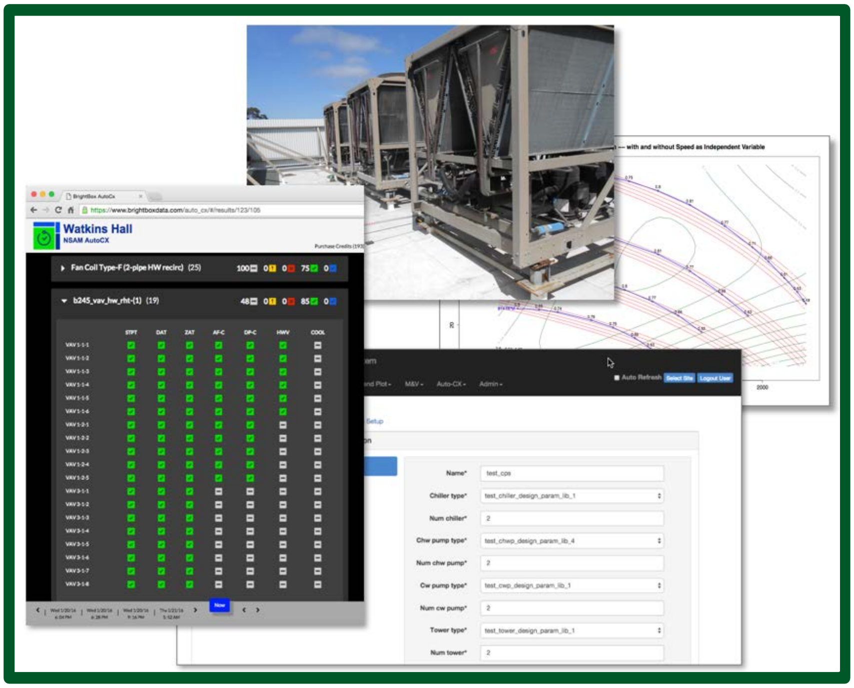
ESTCP
Cost and Performance Report

(EW-201409)



Rapid Deployment of Optimal Control for Building HVAC Systems using Innovative Software Tools and a Hybrid Heuristic/Model-Based Control Approach

March 2017

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ENVIRONMENTAL SECURITY
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14. ABSTRACT

ESTCP project EW-201409 aimed at demonstrating the benefits of innovative software technology for building HVAC systems. These benefits included reduced system energy use and cost as well as improved performance driven by autonomous commissioning and optimized system control. In the end, while many individual elements of the project were completed successfully, the project as a whole was not able to successfully demonstrate the technology.

Anecdotal evidence, academic studies, and system simulations demonstrate the importance and capacity for best-in-class control solutions to improve system performance and reduce energy use and cost. However, implementing these solutions into the extremely heterogeneous and often malfunctioning or misconfigured HVAC systems in real operating buildings poses a major challenge to reaping the benefits promised by advanced control.

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HVAC, BrightBox Optimization Modeling Platform, Theoretical Optimum Plant Power, variable air volume

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COST & PERFORMANCE REPORT
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ACRONYMS AND ABBREVIATIONS

ALC	Automated Logic Corporation (a division of United Technologies)
AutoCx	autonomous commissioning
BOMP	BrightBox Optimization Modeling Platform
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
ESTCP	Environmental Security Technology Certification Program
FNMOC	Fleet Numerical Meteorology and Oceanography Center
HVAC	heating, ventilating, and air-conditioning
NPS	Naval Postgraduate School
NRL	U.S. Naval Research Laboratory
NSAM	Naval Support Activity Monterey
TOPP	Theoretical Optimum Plant Power
VAV	variable air volume

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EXECUTIVE SUMMARY

Environmental Security Technology Certification Program (ESTCP) project EW-201409 aimed to demonstrate the benefits of innovative software technology for building heating, ventilation, and air-conditioning (HVAC) systems. These benefits include reduced system energy use and cost, and improved performance driven by autonomous commissioning (AutoCx) and optimized system control. While many individual elements of the project were completed successfully, ultimately the project was not able to successfully demonstrate the technology.

Two buildings at the Naval Support Activity Monterey (NSAM) facility in Monterey, California, were selected for this demonstration because they met the following criteria:

- Employed an Automated Logic Corporation (ALC) building control system
- Contained HVAC central plants containing multiple chillers with the correct type of control points available and integrated into the ALC system
- Employed variable air volume (VAV) reheat HVAC distribution systems
- Contained existing energy and flow meters to enable monitoring and verification

The first building selected was Building 245 (Watkins Hall). The advanced control solution was not able to be deployed to this building because of chiller equipment failure. The Watkins Hall plant consisted of three chillers: CH-1, CH-2, and CH-3. Despite being co-located, CH-1 served adjacent Building 246, which contains critical security program spaces. During this project, CH-1 became permanently disabled and CH-2 was repurposed to serve Building 246, which left only CH-3 to serve the subject Building 245, making the deployment infeasible.

The second building selected was Building 305 (Glasgow Hall). The advanced control software was not able to be deployed because the chilled-water supply temperature setpoint control point— a key element in deploying the optimal control solution—was not properly configured at any of the three chillers serving this building.

Experience from this project, industry-wide anecdotal evidence, academic studies, and system simulations clearly demonstrate the importance and capacity for best-in-class control solutions to improve system performance and reduce energy use and cost. However, implementing these solutions into the extremely heterogeneous and often malfunctioning or misconfigured HVAC systems in real operating buildings poses a major challenge to reaping the benefits promised by advanced control. For these reasons, BrightBox Technologies efforts were refocused from optimal control toward AutoCx with the goal of establishing a correctly-configured and properly-operating foundation onto which optimal control could eventually be deployed. Unfortunately, an adequate market for AutoCx products was not successfully developed despite the clear need and benefits, as BrightBox Technologies ceased all operations in this market at the end of March 2016.

OBJECTIVES OF THE DEMONSTRATION

The objective was to demonstrate how BrightBox software could be used to quickly and cost-effectively validate correct baseline system configuration and operation, and develop and deploy optimized controls across a wide array of existing buildings. The planned approach was to deploy the BrightBox software at the NSAM. This U.S. Department of Defense (DoD) site represents approximately 1.2 million square feet of space and contains over 25 separate buildings.

No two buildings at NSAM contain identical HVAC systems, and the systems were installed anywhere from 1930 to the present. The systems at NSAM vary, from the simple (baseboard heaters coupled with operable windows) to the complex (multiple-chiller plant serving data centers operating 24/7, large central steam boiler plant). With the help of NSAM staff, a subset of NSAM buildings were identified to receive the BrightBox software, representing an interesting and relevant sample of the buildings on campus. The project objective was for software to be installed in these buildings and the impacts assessed to quantitatively and qualitatively judge the effectiveness of the installation.

TECHNOLOGY DESCRIPTION

The primary objective of the BrightBox software solution was to quickly and correctly develop and implement optimized controls for HVAC systems in existing non-residential buildings. The approach to accomplish this goal consisted of the following elements:

- The BrightBox Optimization Platform, which is a computer modeling language and set of associated algorithms designed specifically for describing and solving complex building controls problems.
- A software platform that created a user interface for the BrightBox Optimization Language, designed with HVAC system templates and objects for quick and accurate modeling
- A communication and data-acquisition interface to existing building control system hardware and software platforms
- A real-time operating system that gathers HVAC system performance data and executes the optimization solver at regularly-scheduled intervals
- AutoCx software that validates basic equipment connectivity and functionality, and control system setup

DEMONSTRATION RESULTS

Individual elements of the technology and deployment platform were successfully developed and tested, but key elements of the system were not able to be deployed to the subject buildings.

The project successfully extended BrightBox software to handle chilled-water plant simulation and optimization, and also partially deployed AutoCx in one of the subject buildings. The project was not able to demonstrate real-time optimization of chiller-plant system controls.

IMPLEMENTATION ISSUES

Malfunctioning equipment in both subject buildings prevented the deployment of the optimal control solution.

1.0 INTRODUCTION

The U.S. Department of Defense (DoD) spends approximately $4 billion per year on facility energy consumption to power and fuel >500 military installations worldwide. These installations include >500,000 buildings and structures. Heating, ventilation, and air-conditioning (HVAC) system energy use across this portfolio represents roughly 40% of these costs, which equates to $1.6 billion annually.

Despite the large number of DoD buildings, each building is unique, and no two buildings contain the same type or configuration of HVAC components and equipment. Contractors install custom HVAC controls in each facility to turn the individual components into functioning systems, and the quality of these control installations directly affects the efficiency and performance of the buildings they serve. Deploying highly optimized custom controls across a wide range of HVAC system types and uses is a challenging but important goal if DoD is to reduce energy costs.

BrightBox Technologies developed an innovative software solution to accomplish this goal while aiming to keep implementation costs low. The BrightBox controls optimization product worked with existing control systems in existing buildings to reduce HVAC energy use and operating costs between 20%–40%. If successfully applied across the entire portfolio of DoD buildings with an average HVAC system performance increase of 25%, this would represent $400 million in annual savings for DoD.

1.1 BACKGROUND

In buildings today, HVAC system controls are not optimized for energy efficiency. BrightBox Technologies developed an innovative approach to writing and deploying building control software that delivers optimized systems quickly and cost-effectively. The technology aimed to deliver 20%–40% HVAC energy cost savings in existing buildings along with performance improvements and other benefits. This Environmental Security Technology Certification Program (ESTCP) demonstration project provided an excellent opportunity for BrightBox to extend product testing and development and demonstrate to the DoD a powerful approach that could potentially be implemented across a large portion of their existing facilities to reduce energy use, reduce utility costs, and improve energy security.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of the project was to demonstrate that BrightBox software could be used to quickly and cost-effectively develop and deploy optimized controls across a wide array of existing buildings. The planned approach was to deploy the BrightBox software at the Naval Support Activity Monterey (NSAM) in Monterey, California. This DoD site represents approximately 1.2 million square feet of space and contains over 25 separate buildings. No two buildings at NSAM contain identical HVAC systems, and the systems were installed anywhere from 1930 to the present. The systems at NSAM vary, from the simple (baseboard heaters coupled with operable windows) to the complex (multiple-chiller plant serving data centers operating 24/7, large central steam boiler plant). With the help of NSAM staff, a subset of NSAM buildings to receive the BrightBox software representing an interesting and relevant sample of the buildings on campus were identified. The project objective was for software to be installed in these buildings and the impacts assessed to quantitatively and qualitatively judge the effectiveness of the installation.

Major performance objectives for the demonstration included (1) reduction of HVAC system energy use by 20%–40% due to BrightBox control-optimization software operation, and (2) identification of baseline system configuration or operational issues using BrightBox AutoCx autonomous commissioning (AutoCx) software. Ultimately, the controls optimization software was not deployed, so no energy savings could be measured. The AutoCx software was partially deployed and, where used, it validated that subject systems were configured and operating correctly.

1.3 REGULATORY DRIVERS

1.3.1 Federal Energy Independence and Security Act (Public Law 110-140)

The Energy Independence and Security Act (Public Law 110-140) from 2007, aims to increase the efficiency of buildings. This project would contribute to that goal.

1.3.2 DoD Strategic Sustainability Performance Plan (SSPP)

The DoD Strategic Sustainability Performance Plan (SSPP) from 2012, with the latest update in fiscal year 2016, established the path by which DoD will improve practices that further the sustainability goals of the nation. In particular, the DoD intends to integrate sustainability into the everyday course of DoD business. The plan requires an annual target reduction of 3% in facility energy intensity across the DoD. This project would contribute to that goal.

1.3.3 Navy Service Policy UFC 1-200-02

Navy Service Policy Unified Facilities Criteria (UFC) 1-200-02 “High Performance and Sustainable Building Requirements” (last updated in December 2016) was specifically created to “drive transformation in the performance of the DOD facility inventory.” Areas of performance include: (1) energy efficiency, (2) optimized energy performance, and (3) measurement and verification. This project makes contributions in each of these performance areas.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

The primary objective of the BrightBox software solution was to quickly and correctly develop and implement optimized controls for HVAC systems in existing non-residential buildings. The planned approach to accomplish this goal consisted of the following elements:

- The BrightBox Optimization Platform, which is a computer modeling language and set of associated algorithms designed specifically for describing and solving complex building controls problems. This optimization platform is based on system optimization research performed at the University of California, Berkeley in the model-predictive controls laboratory led by Dr. Francesco Borrelli. The platform employs continuous optimization techniques applied to implicit systems. These systems are defined with linked physics-based models characterized by parameters that were determined by fitting historical data streams.
- A software platform that created a user interface for the BrightBox Optimization Language, designed with HVAC system templates and objects for quick and accurate modeling
- A communication and data-acquisition interface to existing building control system hardware and software platforms
- A real-time operating system that gathers HVAC system performance data and executes the optimization solver at regularly-scheduled intervals
- AutoCx that validates basic equipment connectivity and functionality, and control system setup. This approach to AutoCx uses the model-based description of the system components and topology to drive a test state-machine to schedule, perform, record, analyze, and report on system validation tests.

2.1.1 AutoCx Development

Over the course of the first two years of BrightBox software development and deployments, it was determined that a robust, systematic method for validating individual component configuration and operational readiness was needed. At first, these issues were discovered in an indirect manner, by debugging system deployments when observed performance did not match the expected. There are cases where component misconfiguration or equipment that was broken was identified; these issues were the cause of reduced performance.

AutoCx was developed in part to actively discover these issues, mimicking the approach used by an operator or technician who would review an installation using the building control system interface. The basic approach is to both passively and actively read/write data to the running systems and then analyze the collected data to see if it matches expectations. Where data does not match, this indicates a system configuration or performance problem with a very low rate of false-positives.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

2.2.1 Performance Advantages

The goal for the BrightBox HVAC optimization technology was to increase energy efficiency by providing optimized control sequence of operation for existing controls infrastructures by updating optimized HVAC control algorithms quickly and on a regular basis (typically every five minutes).

2.2.2 Cost Advantages

As a software solution, BrightBox offers very low up-first costs. Current typical sales cycles involve an offer of a no-cost demonstration to show what the BrightBox software can do. Once energy savings have been quantified, the savings are shared between BrightBox and the customer.

AutoCx delivers the benefits of commissioning to new and existing buildings at a >10x reduction in cost over traditional commissioning deployment methods.

2.2.3 Performance Limitations

BrightBox currently works only by optimizing the controls of existing HVAC equipment. Energy-saving performance could be improved by expanding the BrightBox approach (for customers where it makes economic sense) to also retrofitting and changing installed HVAC equipment. Currently, BrightBox only works with HVAC control systems manufactured by Automated Logic Controls (a subsidiary of United Technologies). In its current form, an active internet connection is required to implement the BrightBox optimization. Future releases may include standalone or non-internet-enabled solutions that may be applicable specifically in the highly secure DoD networks.

One significant limitation to deploying this technology is that the BrightBox optimization system requires the base building systems and components to be installed and working correctly in order for BrightBox to function properly. As was discovered with the Glasgow Hall chillers, if the equipment is not installed or operating correctly, then those issues must be resolved before any optimization can occur.

3.0 PERFORMANCE OBJECTIVES

Performance objectives for this project were set based on the experience to date in commercial buildings. The BrightBox software solution has been deployed in roughly a dozen commercial buildings and savings of 20%–35% of HVAC energy has been achieved. This experience is restricted to packaged HVAC units (not chiller plants). Because an objective of the project was to extend the BrightBox system to include built-up chiller plants, existing data was not available. Therefore, the energy objective was set to the low end of the range: 20% of HVAC energy.

Table 1. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Facility Energy Usage	Energy Intensity (kWh/ft^2)	Meter readings of energy used by installation; square footage of buildings using energy; sub-metered HVAC system data	20% reduction in HVAC system energy use compared to baseline, 7.5% reduction in overall energy use.	No data collected. Demonstration not performed.
System Economics*	Savings to investment ratio (SIR)	Measured reduction in HVAC system energy costs	SIR ≥1.67**	No calculation performed.
BOMP Library Expansion	Number of BOMP Library Components	Number of BOMP Library Components	Expand the BOMP component library to include 13 new components	Only hydronic components completed (5 of 13).
BrightBox Control Software Generation	Models Generated	Models Generated	The BrightBox software will be able to successfully generate new control software automatically for each of the two buildings.	Completed in simulation, not deployed.
TOPP model dataset generation speed	Time to generate TOPP model data	Time to generate TOPP model data using BrightBox platform and Taylor platform	100x improvement in the time to generate TOPP model data using the BrightBox platform versus the Taylor platform.	TOPP data set generation and BrightBox solution generation rougly same time to complete. No improvement.
AutoCx number of objects tested and number of issues found	Number of objects tested and number of issues found	Number of objects tested and number of issues found	All testable objects at the demonstration site have been tested and number of issues found has been field verified.	Half of testable objects tested.
Qualitative Performance Objectives				
Satisfaction with BrightBox Control Software	Facility Surveys (a sample survey is provided in Appendix C)	Positive Responses on User Surveys	Based on survey responses, the facilities staff at NSAM indicate that they feel the new control sequences generated by the BrightBox software are adequate/functional and will remain in use.	No surveys issued.

BOMP – BrightBox Optimization Modeling Platform: an HVAC control system modeling platform developed by BrightBox Technologies
TOPP – Theoretical Optimum Plant Power

*For “System Economics” - Refer to the NIST Building Life Cycle Cost program, available on the DOE website: http://www1.eere.energy.gov/femp/information/download_blcc.html#blcc

** We don’t currently have any sub-metering information to use to make a system economic analysis of the potential economic savings at the start of the project. We only have electric bill information for the one meter that serves the entire NSAM site. We have no information available for any of the individual buildings. As we get into the project, monitor the buildings and apply the BrightBox technology, we will begin to be able to provide estimates of the system economics.

4.0 SITE DESCRIPTION

Home to >15 tenant commands, NSAM (Monterey, California) provides primary support to the Naval Postgraduate School (NPS), the U.S. Naval Research Laboratory (NRL), and the Fleet Numerical Meteorology and Oceanography Center (FNMOC). NPS is the largest producer of advanced graduate degrees for the DoD and proudly graduates thousands of students every year from all Services and from over 50 countries. NRL provides all scientific and weather modeling as well as atmospheric and aerosol studies. FNMOC provides the highest quality, most relevant, and timely worldwide meteorology and oceanography support to U.S. and coalition forces from FNMOC's 24/7 Operations Center in Monterey. NSAM supports over 160 buildings located on over 626 acres.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The demonstration site was NSAM. The largest tenant of NSAM is the NPS. Two buildings assigned to the NPS were chosen for the demonstration project.

4.1.1 Demonstration Site description

NSAM is located relatively close (less than a two-hour drive) to the BrightBox Technologies office in Berkeley, California, which would facilitate easy interaction with site staff and BrightBox presence on the campus as needed. Further, NSAM is served by Sunbelt Controls, a controls contractor partner of BrightBox Technologies and collaborator/channel-partner of the technology platform. Sunbelt Controls has been engaged as an active partner in the ESTCP project, and would be a valuable, knowledgeable, and capable partner in this effort.

The HVAC systems at NSAM are largely controlled with Automated Logic Corporation (ALC) control hardware and software. BrightBox Technologies has partnered with ALC to provide the software as an integrated "plug-in" to the ALC system.

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5.0 TEST DESIGN

Currently HVAC systems in two buildings at NSAM are operating with traditional controls systems. Such systems are reactive in that components react to “state” signals from other components in a control sequence. BrightBox implements a different control approach based on predictive control. The test design centers around comparing energy consumed by the HVAC systems when the traditional reactive control sequences are operating, to energy consumed when the new predictive control sequences are operating.

- Fundamental Problem: The fundamental problem is that traditional HVAC system controls are reactive and do not use models of equipment performance when controlling building systems. BrightBox software optimization based on model predictive control is a new approach to HVAC control that would replace older, traditional methods of HVAC control. A fundamental component of the project is to create a software model within which this optimization of HVAC system controls can exist and evolve.
- Demonstration Question: Can BrightBox software optimization using model-based predictive control be extended to built-up chiller plants in an HVAC system and also save 20% of HVAC energy consumption in two buildings at NSAM?

5.1 CONCEPTUAL TEST DESIGN

Conceptually, the test design to measure the energy consumed by HVAC equipment in two buildings at NSAM with the BrightBox software optimization running and not running. Power consumption, supply and return air and water temperatures, flow rates, and fan speeds will also be measured and used in the model.

5.2 BASELINE CHARACTERIZATION

The baseline characterization was intended to occur during periods of time when the BrightBox optimization software was not operating so that it could be compared to periods of time when the BrightBox software was operating. It was anticipated that several days to one week in each mode would be required to provide adequate baseline-to-test mode ratio data.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The system design centers around remotely administered model-based HVAC controls optimization. The system replaces reactive HVAC controls (controls that react to various inputs) with a predictive model that anticipates how the HVAC system will need to operate based on various data inputs—weather, indoor temperature setpoints, HVAC system component capabilities, cost of energy, etc. After setting an optimization parameter (e.g., the lowest possible energy use, or lowest possible energy cost), the system then constructs the optimal control sequence for that HVAC system for the immediate future. A new control sequence is optimized and uploaded via the internet to the building every five minutes. In the BrightBox initial commercial deployments, 20%–30% HVAC energy savings were typical using this approach.

5.4 OPERATIONAL TESTING

Operational testing of cost and performance is ongoing and continuous. Once the BrightBox models of the HVAC systems are built and operational, they operate continuously unless turned off.

5.5 SAMPLING PROTOCOL

Table 2. Sampling Protocol

Item	Data
Data collector	BrightBox Technologies remotely over the internet
Data recording	BrightBox Technologies remotely over the internet. If the network goes down, any trend data that is required for the operation of the control system is cached locally and can be recovered. Any additional data that BrightBox Technologies might be collecting in realtime would be lost for the period of the network outage.
Data description	Power and energy consumption, supply and return air and water temperatures, flow rates, thermostat values, and fan speeds, etc. Minimum sampling rate of five minutes.
Data storage and backup	BrightBox utilizes cloud services so data backup is continuous and automatic.
Data collection diagram	The data collection for this project is too complex for a diagram to be practical or useful.
Non-standard data	No non-standard data will be collected.
Survey Questionnaires	A user satisfaction survey will be part of this project.

5.6 SAMPLING RESULTS

No sampling results could be obtained due to our inability to deploy the technology to the target buildings.

6.0 PERFORMANCE ASSESSMENT

ESTCP project EW-201409 aimed to demonstrate the benefits of innovative software technology for building HVAC systems to include reduced system energy use and cost, and improved performance driven by AutoCx and optimized system control. While many individual elements of the project were completed successfully, the project as a whole was unable to successfully demonstrate the technology.

The following items were successfully completed as part of this demonstration project:

- Development of technology related to incorporating chilled-water plant elements into the BrightBox system
- Creation of models for air-cooled chiller plant
- Creation of models for chilled-water (and condenser water) pumps
- Creation of models for cooling towers (to validate against the Taylor Engineering software)
- Validation of primary-only variable-flow chilled water system operation
- Expansion of a controls system to include new sensors, meters, and graphic screens at Glasgow Hall and Watkins Hall
- Establishment of secure bi-directional data connection between BrightBox remote secure data-center and the NSAM WebCTRL system
- Deployment of AutoCx at Watkins Hall

The following items were not successfully demonstrated.

- Testing of “air-side” BrightBox system components
- Operation of the BrightBox chilled water system controls optimization

The two buildings at the NSAM facility that were selected for this demonstration met the following criteria:

- Employed an ALC building control system
- Contained HVAC central plants containing multiple chillers with the correct type of control points available and integrated into the ALC system
- Employed VAV-reheat HVAC distribution systems
- Contained existing energy and flow meters to enable monitoring and verification

For the first building selected (Building 245, Watkins Hall), the advanced control solution was not able to be deployed because of chiller equipment failure. The Watkins Hall plant consisted of three chillers: CH-1, CH-2, and CH-3. Despite being co-located, CH-1 served adjacent Building 246, which contains critical security program spaces. During this project, CH-1 became permanently disabled and CH-2 was repurposed to serve Building 246, leaving only CH-3 to serve Building 245, which made the deployment infeasible.

For the second building selected (Building 305, Glasgow Hall), the advanced control software was unable to be deployed because the chilled water supply temperature setpoint control point—a key element in deploying the optimal control solution—was not properly configured at any of the three chillers serving this building.

At Glasgow Hall, NSAM staff, NSAM service contractors, and BrightBox staff were eventually able to diagnose the cause of the malfunctioning control point and measures were identified to repair the equipment. However, before ESTCP could move forward with fixing the equipment, BrightBox Technologies went out of business.

Anecdotal evidence, academic studies, and system simulations clearly demonstrate the importance and capacity for best-in-class control solutions to improve system performance and reduce energy use and cost. However, implementing these solutions into the extremely heterogeneous and often malfunctioning or misconfigured HVAC systems in real operating buildings poses a major challenge to reaping the benefits promised by advanced control. For these reasons, BrightBox Technologies refocused project efforts away from optimal control and toward AutoCx with the goal of establishing a correctly-configured and properly-operating foundation onto which optimal control could eventually be deployed. A market for AutoCx products has not yet been successfully developed despite the clear need and benefits. BrightBox Technologies ceased operations in this market at the end of March 2016, as a result.

7.0 COST ASSESSMENT

7.1 COST MODEL

The BrightBox solution was more similar to the ESSCO model than a traditional life-cycle cost model. The BrightBox technology had no initial cost for the customer. Once the BrightBox technology had been installed and proven, BrightBox would retain a portion of the cost savings. A typical contract would be issued and renewed on an annual basis. If an onsite server had to be installed due to security concerns, responsibility for upfront and maintenance costs would fall to the customer.

Once this project was over, NSAM would have been offered a contract to continue the BrightBox service. No setup fee would be charged. However, a $10,000 setup fee was assumed for the purposes of performing the economic analysis.

BrightBox target cost numbers assumed typical baseline HVAC energy cost of $2/square foot/year. Assuming BrightBox could save 10% of HVAC energy costs on average, that would be $0.2/square foot/year. Other costs would include a setup fee of $10,000/project, $1,000 for operator training, and split of 75% of the savings to BrightBox and 25% to NSAM. The total square footage for Glasgow Hall and Watkins Hall is roughly 225,000 square feet, which implies annual energy costs of $450,000 and associated savings of $45,000. NSAM would keep $11,250 with a simple payback time of just under one year.

- <u>Building Life-Cycle Cost Program</u>: The data from Table 2 along with the assumptions above, a 3% discount rate, and a ten-year lifetime were entered into the U.S. Department of Energy's (DOE's) Building Life Cycle Cost (BLCC) 5 program for analysis. The detailed life-cycle cost report is attached as Appendix F. In summary, over a ten-year lifetime, the base case total life-cycle cost would be $4,748,295, or $513,263/year. The alternate BrightBox case total life-cycle cost would be $4,036,210, or $436,291/year.
- <u>Life-Cycle Cost Table</u>: See Table 3.
- <u>Life-Cycle Cost Elements:</u> The main cost to achieve the savings is the $10,000 installation cost.
- <u>Life-Cycle Cost Timeframe</u>: The timeframe for the life-cycle cost estimate is the DOE default of ten years. While the software itself would not wear out per se, it is anticipated that after a ten-year lifetime, a better solution might be available.

Table 3. Cost Model

Cost Element	Data Tracked During the Demonstration
Hardware capital costs	$0
Installation costs	$10,000
Consumables	$0
Facility operational costs	10% reduction in HVAC energy costs used for this plan, actual energy reduction will be used for final report
Maintenance	$0.10 per square foot per year. For Watkins and Glasgow Halls at 226,111 square feet this is $22,611 per year.
Hardware lifetime	10 years
Operator training	Included in maintenance fee
Salvage Value	$0

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8.0 IMPLEMENTATION ISSUES

The first building selected was Building 245 (Watkins Hall). An advanced control solution was unable to be deployed to this building because of chiller equipment failure. The Watkins Hall plant consisted of three chillers: CH-1, CH-2, and CH-3. Despite being co-located, CH-1 served adjacent Building 246, which contains critical security program spaces. During this project, CH-1 became permanently disabled and CH-2 was repurposed to serve Building 246, which left only CH-3 to serve the subject Building 245, making the deployment infeasible.

The second building selected was Building 305 (Glasgow Hall). The advanced control software was unable to be deployed because the chilled-water supply temperature setpoint control point—a key element in deploying the optimal control solution—was not properly configured at any of the three chillers serving this building.

To resolve the issue at Glasgow Hall, a team consisting of BrightBox engineers, NSAM operations staff, two different NSAM support contractors, and equipment manufacturers was formed to identify the source of the problem and develop a solution. After months of work, the team was able to identify the cause of the problem as the undocumented replacement of a control board inside the chillers that was malfunctioning. This problem dated to the original system installation and was unknown to building operators over the past ten years. A solution was identified and the ESTCP program made funds available to implement the repair.

However, project timing did not allow for this solution to be implemented because at roughly the same time BrightBox Technologies ceased all operations in this market. The situation with the Glasgow Hall chillers highlights the need for thorough documentation of system design intent coupled with commissioning activities to verify that systems are installed, configured, and operating properly.

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APPENDIX A POINTS OF CONTACT

Point of Contact Name	Organization Name	Phone Email	Role in Project
Allan Daly	BrightBox Technologies	510-220-0500 allan@brightboxtech.com	Principal Investigator
Rob Koch	BrightBox Technologies	650-743-2082 rob@brightboxtech.com	Chief Executive Officer
Marc Fountain	BrightBox Technologies	510-681-4778 marc@brightboxtech.com	Project Manager
Mark Hydeman	Taylor Engineering	510-263-1543 mhydeman@taylor-engineering.com	Sub-contractor lead
Rich Phifer	Sunbelt Controls	650-333-8685 rphifer@sunbeltcontrols.com	Sub-contractor lead
Lieutenant Commander (LCDR) Oscar Antillion	NSAM	oscar.antillon@navy.mil	Public Works Officer (lead for NSAM)
Matt Seuss	NSAM	matthew.suess@navy.mil	Deputy Public Works Officer
Michael Fitzgerald	NSAM		Facilities Manager
Erik Abbot	NSAM	erik.abbott@navy.mil	HVAC technician
Douglass Taber, RA, CEM	NSAM	831-656-3653 douglass.c.taber@navy.mil	Demonstration site representative

APPENDIX C SAMPLE SURVEY

Dear NSAM Facilities Management Staff:

BrightBox Technologies has now completed our ESTCP demonstration project at your facility. As part of our agreement with the Department of Defense, we are required to ask for your feedback to help evaluate the success of the project. Please take a moment to complete the brief survey below and return to Marc Fountain, BrightBox Technologies 2040 Bancroft Way Suite 302, Berkeley, CA 94704 or marcfountain@comcast.net

1) Did you find the BrightBox software easy to work with?

1	2	3	4	5
Difficult	Somewhat difficult	Neither difficult nor easy	Somewhat easy	Extremely easy

2) Did any issues come up with the software that were difficult to resolve?

1	2	3	4	5
Difficult	Somewhat difficult	Neither difficult nor easy	Somewhat easy	Extremely easy

(please elaborate)

3) Were the promised energy savings realized or exceeded?

1	2	3	4	5
Not realized	Somewhat realized	Realized	Somewhat exceeded	Extremely exceeded

4) Were the promised cost savings realized or exceeded?

1	2	3	4	5
Not realized	Somewhat realized	Realized	Somewhat exceeded	Extremely exceeded

5) Would you recommend BrightBox to a colleague?

1	2	3	4	5
Definitely not	Probably not	Undecided	Probably	Definitely

6) Any other comments for the BrightBox team?

Thank you for your feedback!

APPENDIX F BLCC5 LIFE CYCLE COST ANALYSIS

12.0 NIST BLCC 5.3-13: DETAILED LCC ANALYSIS

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

12.1 GENERAL INFORMATION

File Name:	C:\Program Files\BLCC5\projects\NSAM.xml
Date of Study:	Tue Apr 14 11:12:41 PDT 2015
Analysis Type:	FEMP Analysis, Energy Project
Project Name:	NSAM
Project Location:	California
Analyst:	Marc
Base Date:	January 1, 2015
Service Date:	January 1, 2016
Study Period:	11 years 0 months (January 1, 2015 through December 31, 2025)
Discount Rate:	3%
Discounting Convention:	End-of-Year

Discount and Escalation Rates are REAL (exclusive of general inflation)

13.0 ALTERNATIVE: BASE CASE

13.1 INITIAL COST DATA (NOT DISCOUNTED)

13.1.1 Initial Capital Costs

13.1.1.1.1 (adjusted for price escalation)

Initial Capital Costs for All Components: $0

13.1.1.2 Component:

13.1.1.2.1. Cost-Phasing

Date	Portion	Yearly Cost
January 1, 2015	100%	$0
	------------	------------

Total (for Component)	$0

13.1.2. Energy Costs: Electricity

13.1.2.1.1 (base-year dollars)

Average Annual Usage	Price/Unit	Average Annual Cost	Average Annual Demand	Average Annual Rebate
5,625,000.0 kWh	$0.08000	$450,000	$120,000	$0

13.2 LIFE-CYCLE COST ANALYSIS

	Present Value	Annual Value
Initial Capital Costs	$0	$0
Energy Costs		
Energy Consumption Costs	$3,748,654	$405,208
Energy Demand Charges	$999,641	$108,055
Energy Utility Rebates	$0	$0
	------------	------------
Subtotal (for Energy):	$4,748,295	$513,263
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Operating, Maintenance & Repair Costs		
Component:		
Annually Recurring Costs	$0	$0
Non-Annually Recurring Costs	$0	$0
	------------	------------
Subtotal (for OM&R):	$0	$0
Replacements to Capital Components		
Component:	$0	$0
	------------	------------
Subtotal (for Replacements):	$0	$0
Residual Value of Original Capital Components		
Component:	$0	$0

	------------	------------
Subtotal (for Residual Value):	$0	$0
Residual Value of Capital Replacements		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Total Life-Cycle Cost	$4,748,295	$513,263

13.2.1 Emissions Summary

Energy Name	Annual	Life-Cycle
Electricity:		
CO2	1,479,019.47 kg	14,788,170.00 kg
SO2	364.55 kg	3,645.00 kg
NOx	607.58 kg	6,075.00 kg
Total:		
CO2	1,479,019.47 kg	14,788,170.00 kg
SO2	364.55 kg	3,645.00 kg
NOx	607.58 kg	6,075.00 kg

14.0 ALTERNATIVE: BRIGHTBOX

14.1 INITIAL COST DATA (NOT DISCOUNTED)

14.1.1 Initial Capital Costs

14.1.1.1.1 (adjusted for price escalation)

Initial Capital Costs for All Components: $10,000

14.1.1.2 Component:

14.1.1.2.1 Cost-Phasing

Date	Portion	Yearly Cost
January 1, 2015	100%	$10,000
	------------	------------

Total (for Component)	$10,000

14.1.2 Energy Costs: Electricity

14.1.2.1.1 (base-year dollars)

Average Annual Usage	Price/Unit	Average Annual Cost	Average Annual Demand	Average Annual Rebate
5,062,500.0 kWh	$0.08000	$405,000	$60,000	$0

14.2 LIFE-CYCLE COST ANALYSIS

	Present Value	Annual Value
Initial Capital Costs	$10,000	$1,081
Energy Costs		
Energy Consumption Costs	$3,343,591	$361,423
Energy Demand Charges	$495,347	$53,544
Energy Utility Rebates	$0	$0
	------------	------------
Subtotal (for Energy):	$3,838,938	$414,967
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Operating, Maintenance & Repair Costs		
Component:		
Annually Recurring Costs	$187,272	$20,243
Non-Annually Recurring Costs	$0	$0
	------------	------------
Subtotal (for OM&R):	$187,272	$20,243
Replacements to Capital Components		
Component:	$0	$0
	------------	------------
Subtotal (for Replacements):	$0	$0
Residual Value of Original Capital Components		

Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Residual Value of Capital Replacements		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Total Life-Cycle Cost	$4,036,210	$436,291

14.2.1 Emissions Summary

Energy Name	Annual	Life-Cycle
Electricity:		
CO2	1,331,117.52 kg	13,309,353.00 kg
SO2	328.09 kg	3,280.50 kg
NOx	546.82 kg	5,467.50 kg
Total:		
CO2	1,331,117.52 kg	13,309,353.00 kg
SO2	328.09 kg	3,280.50 kg
NOx	546.82 kg	5,467.50 kg

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